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The effect of microwave radiation on the triboelectrostatic separation of coal

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Abstract

The triboelectrostatic separation and extraction of Slovak brown coal samples—untreated and microwave-treated, were analyzed. The changes in the coal structure as a result of interaction between the microwave radiation and the coal facilitated improvements to the process of separation and extraction of the coal. In the case of microwave-treated coal at a power of 900 W for a period of 10 min it was possible to obtain increased content of volatile substances to 44 wt% compared to 30 wt% in the untreated sample and decrease of ash content from 49 to 18.3 wt%. The quality of triboelectrostatic separation of microwave irradiated and non-irradiated coal samples was evaluated by comparing the recoveries of the combustible matter and ash. The influence of microwaves on the extraction of coal was also positive: the preliminary thin layer chromatographic analysis of 2 min microwave irradiated and non-irradiated coal extracts confirmed the effect of microwaves on qualitative organic matter composition in the extracts utilizable for special purposes.

Keywords: Microwave pre-treatment; Triboelectrostatic separation; Slovak brown coal

1. Introduction

The microwave heating of raw materials is a progressive treatment technology [1]. The favourable effect of microwave treatment was observed in the desulphurisation [2] and drying of coal [3,4]. The desulphurisation of Slovak brown coal using microwave radiation has been described in detail [5].

The effect of microwave treatment on the coal disintegration process was described by Marland [6]. According to this author the organic component of the coal is a relatively poor absorber of microwave energy. However, depending upon the microstructure and geological location, coals naturally also contain water to varying degrees and water is considered to be a good absorber of microwave energy. When microwaves are applied, the molecular dipoles of water align and flip around as the applied field is alternating. Their movement produces frictional heating [7]. The water molecules are heated up, change the phase and expand creating internal pressure in the coal matrix, possibly weakening the structure of coal. Mineral matter components in coal differ in their ability to absorb the microwave energy. Some minerals readily heat in the applied microwave field (for example, pyrite has an average heating rate of 1.89 °C/s when exposed to a microwave field at a power of 650 W and frequency of 2.45 GHz); other minerals appear transparent to microwave radiation (quartz has an average heating rate of only 0.07 °C/s) under the same conditions [8–10].

Soong [11] described the principle of the triboelectrostatic separation of brown coal, which is very effective in producing cleaned coals. It was found out that the degree of ash removal and combustible recovery depends on the type of coal.

The present paper describes the effect of microwave treatment on Slovak brown coal and its influence on the subsequent triboelectrostatic separation and extraction.

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2. Experimental

2.1. Material

The experiments were carried out with a Slovak brown coal sample from Cígel. The chemical analysis of elements, ash and volatile matter were realized as follows: the ash and volatile matter were determined by thermogravimetric analysis, while the carbon, hydrogen and nitrogen were determined by gas chromatography. The chemical composition of the brown coal is shown in Table 1. The specific surface of the coal samples studied was determined by low temperature nitrogen adsorption (BET). The particle size distribution of the ground microwave untreated as well as microwave-treated coal was measured by the method of laser radiation scattering.

2.2. Microwave treatment

Coal sample of particle size less than 3 mm was heated, before electrostatic separation, for 10 min in the microwave oven with maximum power of 900 W, at 2.45 GHz in nitrogen atmosphere to avoid oxidation by air. The temperature was measured by non-contact thermometer in the range 120–150 °C. After microwave heating the sample was ground to the −70 μm. The coal sample before extraction was heated for 2 min at the power of 900 W in the temperature range 200–220 °C.

2.3. Coal samples extraction and extracts chromatographic separation

Five grams of brown coal were Soxhlet extracted in toluene–methanol mixtures for 72 h at 90 °C. Microwave-treated and untreated coal sample extracts were then concentrated to a volume of 0.2 ml by solvent evaporation and analysed by thin layer chromatography (TLC). Five microliters of each extract (repeated three times) was applied to RP-18 thin layer (Merck, Germany) and followed with chromatographic separation at optimised conditions (developer vapour pressure, temperature, mobile phase composition). The analytes separated were primarily detected with UV at 254 nm after developing and layer drying.

Table 1
Chemical composition of Slovak brown coal from Cígel

Content (wt.%)	Cígel (Slovakia)
Ash	49.0
Carbon	27.7
Hydrogen	3.4
Nitrogen	0.5
Oxygen	18.3
CaO	1.47
MgO	0.94
SiO_2	31.70
Al_2O_3	9.49
Fe_2O_3	3.30
Na_2O	0.30
P_2O_5	0.06
TiO_2	0.31
K_2O	1.13
Volatiles	30.0
Total sulfur	1.37
Sulfate sulfur	0.28
Pyritic sulfur	0.49
Organic sulfur	0.6

2.4. Triboelectrostatic separation

The triboelectrostatic method was developed in the USA (see Figs. 1 and 2) with a totally pneumatic system without mechanical charging devices [12]. The separator consists of Venturi feed system driven by nitrogen pressure, an injection nozzle and a high voltage separation section. The coal particles pass through Venturi feeder and become charged in this turbulent flow zone due to the contact with the cooper tubing and with one another. The contact of these particles with copper surfaces results in an effective charging of both coal and mineral impurities. These charged particles are then forced out of the nozzle in a ribbon of entrained particles approximately in the area $7.62 \times 0.3175\ cm^2$. This plume of particles is directed between two parallel charged plates 15.24 cm long and 7.62 cm apart. For coal separation the unit is operated at + or −25.000 volts on the separator plates. The positively charged coal particles are attracted to the negative electrode and the negatively charged mineral particles are moved to the positive electrode. A splitter is placed 15.24 cm downstream from the nozzle to separate fractions rich in coal and ash and direct them to two collection cyclones. The entire separator is swept with laboratory air by applying vacuum to the outlets of the collection cyclones. The sweep flow enters the separator through flow straighteners around the nozzle to control the flow in the separator section. This separator has a capacity of about 8 kg/h in continuous operation and can be used in the batch mode using as little as 100 g of coal feed with granularity less than 70 μm. The separations were carried out using the injector in three positions with respect to the splitter position—centered, displaced 0.635 cm towards the positive plate and displaced 0.635 cm towards the negative plate. The cleaned coal (attracted to the negative electrode) and refuse fractions (attracted to the positive electrode) generated in these three runs, together with the feed were then analyzed for carbon, ash, sulfur and volatile matter by standard chemical methods.

3. Results and discussion

The microwave treatment does not cause any considerable change in the specific surface, which was 6.51 $m^2\ g^{-1}$

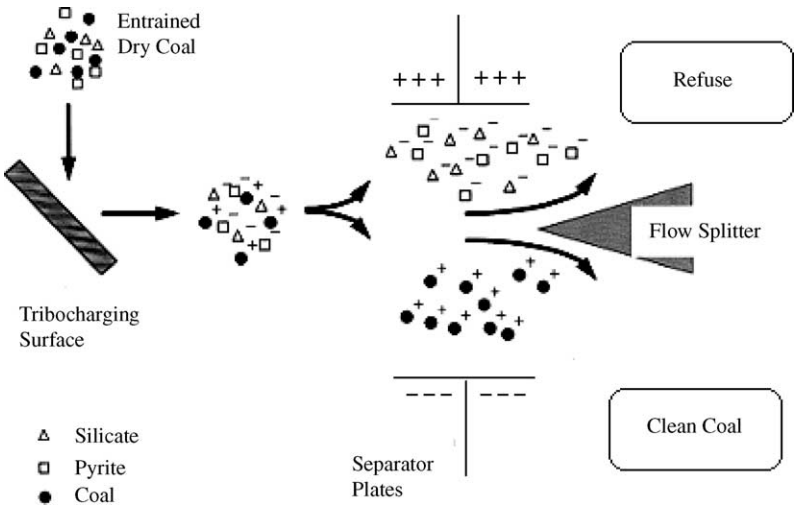

Fig. 1. Principles of triboelectrostatic separation.

for the irradiated sample and 6.41 $m^2 g^{-1}$ for the non-irradiated sample. The granulometric characteristics of non-treated as well as microwave-treated coal samples are shown in Figs. 3 and 4. The density distribution of the volume yield of treated sample confirms that it comes from the destruction of higher grain-size classes.

It is known that the intensive grinding of coal [13,14] results in considerable changes in the chemical structure of coal and it can be expected that the changes in coal structure can also be caused by microwave irradiation. This was partially confirmed with the results from the TLC analyses.

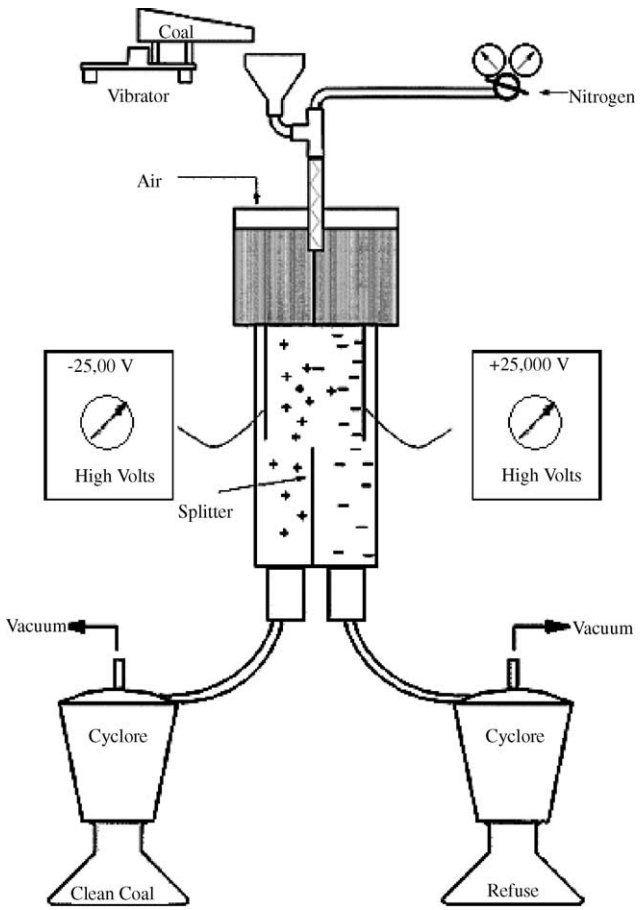

Fig. 2. Schematic drawing of triboelectrostatic separator.

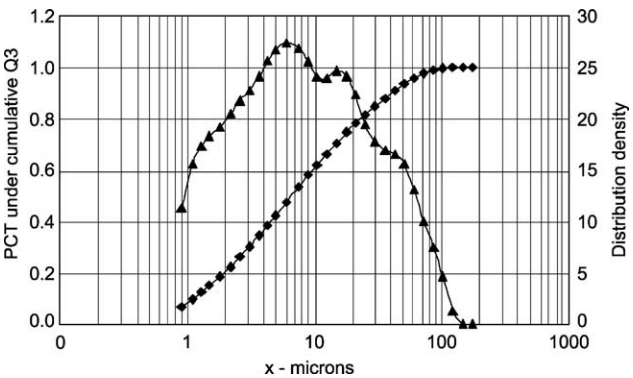

Fig. 3. Granulometric characteristics of non-treated coal sample.

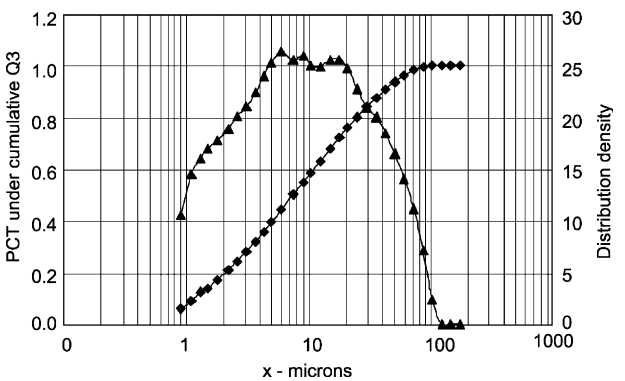

Fig. 4. Granulometric characteristics of microwave-treated coal sample.

Table 2
Qualitative distribution of organic matters fractions in extracts from microwave-treated and untreated coal samples

Sample	Ret. factor	Toluene content in extraction agent: toluene–methanol (%, v/v)							
		15	30	40	45	60	75	80	90
Non-treated	R_f	Start	0.218	–	0.379	0.527	0.685	0.181	0.129
					0.472	0.627	–	–	–
MW-treated		Start	0.218	0.327	–	0.545	0.648	0.600	0.129
			0.454	0.436	0.462	0.679	0.740	–	–

Table 3
Characteristics of untreated and microwave-treated sample of the brown coal after triboelectrostatic separation

	Untreated sample							Microwave-treated sample						
	Feed	C^+	C^-	R^+	R^-	L^+	L^-	Feed	C^+	C^-	R^+	R^-	L^+	L^-
Weight (g)	100	60	36	69	22	43	57	100	49.7	42.7	65.3	31.2	36.9	55
Moisture (wt%)	7.5	8.6	9.6	7.3	8.3	8.7	9.1	6.6	6.2	6.9	6.1	6.9	6.2	6.8
Volatile (wt%)	30	29	–	–	42	29	36	44	41.5	45	42.7	45	41.5	44.2
Ash (wt%)	49	48	36	49	33	48	40	18.3	22	12.2	20.5	11.9	22.9	13.6
Fixed C (wt%)	14	14	20	–	13	14	14	31.2	30.4	36	30.8	36.6	29.4	35.4
Sulphur (wt%)	1.37	1.3	1.6	1.4	1.6	1.3	1.6	–	–	–	–	–	–	–
Rec. com. (wt%)	–	–	44	–	28	–	66	–	–	46	–	34	–	58
Rec. ash (wt%)	–	59	–	70	–	42	–	–	60	–	73	–	46	–

C, center position of splitter; R, L, right and left position of the splitter displaced 0.635 cm from the center; + and − are positive and negative plate sides.

Microwave-treated coal extracts contained different organic fractions characterised by different chromatographic parameters to those obtained from untreated coal sample extracts. Qualitative composition of fractions increased in methanolic extraction agents (60–70% of methanol) and 75% toluene containing extraction agent (Table 2) for the microwave-treated coal sample. Microwave radiation had a positive effect as regards extractability from the coal matrix.

Table 3 shows the treatment characteristics through triboelectrostatic separation. The highest content of volatile substances in the product of separation of the original sample was observed at the right position of splitter R^-. At the same position of splitter, the carbon content is very low and reaches only 13 wt%. The content of volatiles for the microwave-treated sample at the same position of the splitter is 45 wt% and the content of fixed carbon is the highest at 36.6 wt%. From the point of view of efficiency of separation, the measurement of the recovery of combustible matter of cleaned products is important. Comparing the effects of separation of microwave heated and original samples showed: the highest recovery of combustible matter in the feed of original coal sample was 66 wt% and the level of ash was 40 wt% at the left position of splitter L^-. By moving the splitter to the central position C^- the ash was reduced to 36 wt% and the combustibles recovery 44 wt%. The separation of microwave-treated sample at the left position of the splitter L^- gave 58 wt% of combustibles and 13.6 wt% ash. Similarly, changing the position of the splitter to the center, C^-, the ash at 12.2 and 46 wt% of combustibles were observed.

4. Conclusion

Microwave heating of coal is advantageous for subsequent triboelectrostatic separation. The influence of microwave radiation on coal was confirmed by the increase of the content of volatile substances from 30 to 44 wt% and a decrease of the ash from 49 to 18.3 wt%. The analysis of fractions after triboelectrostatic separation showed that at the central position of the splitter the ash and combustible matter in the non-treated sample was 36 and 44 wt%, respectively. At the same position of the splitter the ash and combustible recovery in the microwave-treated sample were 12.2 and 46 wt%, respectively.

Preliminary thin layer chromatographic analysis of coal extracts confirmed the effect of microwaves on qualitative organic matters composition, which increased in methanolic extraction agents (60–70% of methanol) and in 75% toluene extraction agent. This research is important from the point of the extraction of rare organic substances with biological activity used for special pharmaceutical purposes.

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